

# Magnetic fields and the large-scale structure

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## Abstract

The large-scale structure of the Universe has been observed to be characterized by long filaments, forming polyhedra, with a remarkable 100-200 Mpc periodicity, suggesting a regular network. The introduction of magnetic fields into the physics of the evolution of structure formation provides some clues to understanding this unexpected lattice structure. A relativistic treatment of the evolution of pre-recombination inhomogeneities, including magnetic fields, is presented to show that equivalent-to-present field strengths of the order of  $10^{-8}$  G could have played an important role. Primordial magnetic tubes generated at inflation, at scales larger than the horizon before recombination, could have produced filamentary density structures, with comoving lengths larger than about 10 Mpc. Structures shorter than this would have been destroyed by diffusion due to the small pre-recombination conductivity. If filaments constitute a lattice, the primordial magnetic field structures that produced the post-recombination structures of matter, impose several restrictions on the lattice. The simplest lattice compatible with these restrictions is a network of octahedra contacting at their vertexes, which is indeed identifiable in the observed distribution of superclusters.

The very large structure of the Universe is characterized by filaments and voids. In supercluster distribution maps, such as those by Tully et al. (1992) and Einasto et al. (1997), one can identify filaments larger than  $600 h^{-1} Mpc$ , such as the one connecting the Tucana and the Ursa Major superclusters, probably extended to the Draco supercluster. With galactic peculiar velocities of less than  $10^3 km/s$ , in a time of the order of Hubble's, a galaxy is only able to travel about 10 Mpc. Therefore it is difficult to explain how the primordial mass inhomogeneities could be rearranged from a chaotic distribution to one with ordered alignments. Galaxies, or their pre-galactic inhomogeneities, have no time to redistribute themselves. Present

hydrodynamic forces, and particularly magnetic forces, have had no time to produce a redistribution and explain the large scale structures.

These large structures are also much larger than the horizon at Recombination (about 10 Mpc, comoving length), which implies they could have been originated only at the Inflation epoch. Inflation magnetogenesis is one of the most interesting possibilities for the origin of cosmic magnetic fields (Turner & Widrow 1988; Ratra 1992; Garretson, Field, & Carrol 1992; Dolgov 1993; Gasperini & Veneziano 1995 and others). If present magnetic fields do not have an important influence on the 100 Mpc large-scale structure, there remains the interesting possibility that they were important in the past. In this paper, we analyze the effects of primordial magnetic fields on the present large-scale density distribution.

The history of magnetic fields during the different epochs of the Universe is a complicated one, in which the Radiation Dominated Epoch was critical, as the electron-photon interaction was responsible for a resistivity capable of destroying small scale fields (Lesch & Birk 1998). Magnetic diffusion induced by a finite scalar conductivity cannot affect large scale fields because it doesn't have sufficient time. It is likely that field structures larger than comoving 3 kpc were able to survive and, with complete certainty, structures larger than the horizon survived this hostile epoch.

Some of these field structures became sub-horizon after Recombination and were not destroyed because, in this epoch, the assumption of infinite conductivity is reasonably satisfied and magnetic diffusivity is negligible at all scales.

As shown by Battaner, Florido & Jimenez-Vicente (1997) and Florido & Battaner (1997), primordial magnetic flux tubes were able to induce filamentary radiative energy density inhomogeneities during the radiative epoch between Annihilation and Recombination, or more precisely until the so-called Acoustic Epoch. Magnetic flux tubes arise in cosmic MHD systems and are the  $\vec{B}$ -structures necessary when magnetic coherence cells exist. They anisotropically affect photon distribution because magnetic fields are present in the energy-momentum tensor.

Energy density distributions created during this epoch produced potential wells and seeds for baryonic and CDM inhomogeneities. They originally consisted of filaments. Post recombination non-linear and imperfect fluid effects distorted these structures, but the largest ones were relatively unaffected and should be recognizable today. Moreover, the original primordial magnetic flux tubes were distorted by small scale effects, such as field amplification in growing  $\rho$ -inhomogeneities, ejections by radio galaxies and other

effects, which again, kept the very large scales relatively unaffected. Therefore, both the density and the magnetic field large structures would have survived and should be recognizable today.

A linear perturbation of the Maxwell, conservation of momentum-energy and Einstein Field equations was carried out by Battaner, Florido & Jimenez-Vicente (1997) to study the evolution of magnetic field and density inhomogeneities during the Radiation dominated era, even if not all these equations are independent. The perturbed Robertson-Walker metrics in a plane universe was considered.

A mean cosmological magnetic field cannot exist but a mean magnetic energy density  $\langle B^2/8\pi \rangle$  may be non-vanishing. Provided that this is negligible compared with the radiative energy density, the general laws of expansion ( $R \propto t^{1/2}$ ) and cooling ( $T \propto R^{-1}$ ) are unaffected by the presence of a magnetic energy.

During this epoch, the magnetic field strength always decreases, being diluted by expansion, but the shape of the structures remains unmodified in the expansion. The distribution of  $\vec{B}_0 = \vec{B}R^2$ , where  $R$  is the cosmological scale factor, taking its present value as unity, is constant. This field,  $\vec{B}_0$ , would coincide with the present field only if the complicated post-recombination effects had not distorted the structures and amplified the field.

The equivalent-to-present magnetic field strength during the radiation dominated era should be of the order of  $10^{-8}G$ . If it were less than this, then magnetic fields would have no influence on the structure. If higher, the growth of galaxies and clusters would have proceeded too efficiently. A primordial magnetic flux tube with  $10^{-8} G$  at its centre would produce a density filament with a relative over-density of  $\delta = 5 \times 10^{-4}$  at Recombination, starting with complete density homogeneity, or considering primordial isocurvature inhomogeneities. After Recombination  $\delta$  has increased without the influence of magnetic fields. These would have increased from  $B_0 \sim 10^{-8}G$  before Recombination to  $B_0 \sim 1 - 3 \times 10^{-6} G$  at present, as observed in clusters and in the intercluster medium (Kronberg, 1994). A rough scheme is depicted in figure 1.

It is an observational fact that large scale filaments form polyhedra which form a lattice (Broadhurst et al. 1990; Tully et al. 1992; Einasto et al. 1997 and references therein). Battaner & Florido (1997) considered the properties of this lattice, as if they were produced by primordial magnetic flux tubes, as present filaments would have inherited the topological characteristics of the primordial tubes. They concluded that the simplest network matching the

magnetic restrictions consists of octahedra only contacting at their vertexes.

If the real structures actually consisted of such octahedra, the present supercluster distribution would remain as in an egg-carton Universe. Battaner, Florido & Garcia-Ruiz (1997) identified octahedra only contacting at their vertexes in the real sky as being all the important superclusters and all the important voids (taken from the ETJEA, i.e. Einasto et al. 1997, and the EETDA, i.e. Einasto et al. 1994 catalogues, respectively) forming part of the web. Therefore, the egg-carton network is perfectly recognizable in the present large-scale structure. The size of the octahedra would be  $150h^{-1}Mpc$ .

As shown by Battaner (1998) this network is compatible with a fractal structure, there being sub-octahedra within the octahedra, and so on. The lower limit of the fractal range could be about 10 Mpc, because filaments smaller than that probably had no chance of surviving the Radiation Dominated era. The upper limit is that imposed by observations and even by the present horizon. The fractal dimension would be either 1.77 or 2 depending on the ratio of octahedra/sub-octahedra sizes.

## Conclusions

Though some of the above ideas seems to be rather speculative, it is very noticeable that the cosmic wave actually matches the theoretical results. Our basic conclusion is that primordial magnetic fields have played an important role in establishing the presently observed supercluster network.

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